Computers & Education 135 (2019) 1–14

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Student acceptance of virtual laboratory and practical work: An extension of the technology acceptance model

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ARTICLE INFO

Keywords:
Virtual laboratories
Online practical work
Simulations
Online learning environments
Technology acceptance model

ABSTRACT

The development of Internet technologies and new ways of sharing information has facilitated the emergence of a variety of elearning scenarios. However, in technological areas such as engineering, where students must carry out hands-on exercises and laboratory work essential for their learning, it is not so easy to design online environments for practicals. The aim of this experimental study was to examine students' acceptance of technology and the process of adopting an online learning environment incorporating web-based resources, such as virtual laboratories, interactive activities, and educational videos, and a game-based learning methodology. To this end, their responses to an online questionnaire (n = 223) were analyzed using structural equation modeling. The study was based on the technology acceptance model (TAM), but included and assessed other factors such as perceived efficiency, playfulness, and satisfaction, which are not explained by the TAM. Our results confirm that this extension of the TAM provides a useful theoretical model to help understand and explain users' acceptance of an online learning environment incorporating virtual laboratory and practical work. Our results also indicate that efficiency, playfulness, and students' degree of satisfaction are factors that positively influence the original TAM variables and students' acceptance of this technology. Here, we also discuss the significant theoretical and spractical implications for educational use of these web-based resources.

1. Introduction

Educational technologies and e-learning systems have been adopted by the majority of higher education institutions. Even in face-to-face classes, students are increasingly being asked to use new e-learning formats such as management systems or communications networks. However, e-learning is not so easy on science and technology courses such as engineering, which involve laboratory practicals in addition to theoretical lectures, and where students' hands-on exercises and laboratory work form crucial aspects of their learning. In these fields, virtual laboratories, simulators, and interactive tools are essential to provide students with virtual practical work (Duan, Ling, Mir, Hosseini, & Gay, 2005; Potkonjak et al., 2016).

On the other hand, it should also be noted that laboratory classes are very costly and time-consuming because they require expensive materials or machinery and are usually taught to small groups.

For these reasons, we have designed and developed from scratch an online learning environment (OLE) with web-based

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https://doi.org/10.1016/j.compedu.2019.02.010
Received 2 August 2018; Received in revised form 14 December 2018; Accepted 18 February 2019
Available online 23 February 2019
0360-1315/

applications (Estriegana-Valdehita, Barchino-Plata, & Medina-Merodio, 2017) to facilitate virtual laboratory and practical work, thus extending teacher-supervised learning beyond the classroom walls. Our OLE includes virtual laboratory activities, simulators, hands-on exercises, and teaching videos with which students can learn and practice at their own pace, wherever and whenever they want, with better access than a front row seat. This autonomous study provides a better starting point for meaningful learning in the classroom, enabling students to carry out participative and collaborative tasks in class.

The adoption of these innovative learning and training tools has the potential to increase students' understanding, create opportunities for discussion in the classroom, develop students' competences by means of practical experiences, and improve learning outcomes. However, such expectations come to nothing if students are not very interested in using them. The best tool will fail if it does not stimulate students' interest or motivate them to use it. Hence, it is necessary to understand students' potential acceptance or rejection of an OLE and determine the factors that influence their adoption of this technology. Therefore, the main objective of our study was to gain an insight into students' acceptance of technology and the process involved in their adoption of an OLE incorporating virtual laboratories, interactive exercises, teaching videos, and game-based learning tools, using a model based on the TAM (Davis, 1986, 1989; Venkatesh & Davis, 2000).

This paper is structured as follows: Section 2 contains a literature review and Section 3 presents the model used and the study hypotheses. Section 4 describes the research methodology, the instrument employed, the participants, and data collection, while the data analysis is presented in Section 5. A discussion follows in Section 6 and the paper ends with the conclusions drawn from the study.

2. Literature review and theoretical framework

Breakthroughs in the Information and Communication Technologies offer many solutions, some of which have proved very effective in higher education, enhancing learning, enabling flexible and autonomous learning, and providing students with hands-on and laboratory work experience. Below, we review three different approaches to e-learning resources: virtual computer laboratories or simulations, teaching videos, and game-based learning.

2.1. Learning resources

The most common option for integrating e-learning resources is a learning management system (LMS) such as Moodle or Blackboard. However, although there are some examples of virtual or remote laboratories in a LMS (e.g., Saenz, Chacon, De La Torre, Visioli, & Dormido, 2015; Sousa, Alves, & Gericota, 2010), in general, these platforms are excessively rigid and therefore unsuitable for integrating these resources.

Another widespread option to integrate, distribute, and manage non-face-to-face practical work is to develop a virtual or online learning environment based on web applications. The advantages offered by OLEs in higher education have been extensively studied and documented in recent years, finding that these new technological tools enhance education quality by increasing teacher effectiveness, improving student performance (e.g., Lai & Hong, 2015; Livingstone, 2012; Thompson, 2013), and providing flexible and accessible learning content (e.g., Wu, Tennyson, & Hsia, 2010).

2.1.1. Virtual laboratories, simulators, and hands-on exercises

In many areas of knowledge, but especially in eminently practical and technological fields such as engineering, laboratory work forms an indispensable component of learning (Duan et al., 2005; Potkonjak et al., 2016). In these disciplines, students must devote much of their learning time to solving practical problems and simulating experiences. Learning activities with hands-on exercises in which students play an active role engage and motivate them more effectively than learning activities where they are passive. Therefore, it is necessary to design learning tools that provide students with practical opportunities to research and learn how things work. This same conclusion has been reached by several authors, most of whom have suggested that the solution is to develop web-based virtual laboratories. Some examples include remote experimentation applied to control engineering education (e.g., Vargas et al., 2011) and a web-based virtual electrical machine laboratory for electrical engineering laboratory courses (e.g., Tanyildizi & Orhan, 2009).

According to Sheorey (2014), properly designed virtual experiences and practicals may even replace real-life experimentation. Similarly, Brinson (2015) compared learning outcomes using a traditional and a virtual, remote laboratory. His findings suggest that learning outcomes are equal or better using virtual or remote versus traditional laboratories across all learning outcome categories. In a similar study, Kolloffel and de Jong (2013) found that students using a virtual laboratory acquired a better conceptual understanding and also developed better procedural skills than students using a traditional laboratory. De la Torre, et al. (2013) have suggested that virtual or remote laboratories can enhance the accessibility of experimental setups, providing a distance teaching framework that meets the students' hands-on learning needs. Many other studies have also reported that virtual laboratories and simulations are efficient tools, endowing engineering students with hands-on learning experiences and practical tools (e.g., Ekmekci & Gulacar, 2015), providing opportunities for autonomous learning and practical experience of problem-solving (e.g., Sell & Seiler, 2012), improving student motivation, reducing teaching load, and facilitating the learning process (e.g., Chu & Fang, 2015). Virtual laboratories can also enhance the potential of distance learning to increase flexibility and accessibility.

2.1.2. Teaching videos

Video is one of the most widely used and powerful virtual learning tools (Giannakos, 2013). Clear examples are the countless video tutorials on any subject available on general channels such as YouTube, Vimeo, Yahoo Video, Viddler, and Screencast, and on specialized educational channels such as School Tube, Teacher Tube, Teacher TV, TED-Ed, the Khan Academy, and MIT Open Courseware. MOOCs are another example where video is used as a fundamental tool for learning. In addition, many universities now use video in a wide variety of ways, deploying an enormous range of innovative strategies in the teaching-learning process, distance education, hybrid teaching environments, and in face-to-face teaching environments as a means to complement the curriculum or as an autonomous learning tool to reinforce sometimes complex concepts.

The results of many studies have demonstrated that videos are an effective and useful learning tool providing significant knowledge gains (Kay & Kletskin, 2012), student satisfaction, and improved learning outcomes (Wells, Barry, & Spence, 2012), and leading to the acquisition of significantly better practical skills (Donkor, 2010). Combined with class attendance, online educational video has a positive impact on student performance (Wieling & Hofman, 2010). Videos extend the teacher's explanations beyond the classroom walls and endow students with temporal and spatial flexibility, enabling them to reflect and learn at their own pace.

2.1.3. Game-based learning

The primary goal of game-based learning is to increase students' interest and motivation through aspects such as competition and thus engage students in the learning processes. Game elements such as badges, content unlocking, avatars, collections, gifting, level progressions, quests, social graphs, and virtual goods are used in learning activities to achieve educational objectives (Buckley & Doyle, 2017).

Interest in game-based learning continues to grow because people, and particularly students, can learn many things through games (de-Marcos, Garcia-Lopez, & Garcia-Cabot, 2016). Several authors have investigated the positive effect of rewards to motivate and engage students (e.g., Auvinen, Hakulinen, & Malmi, 2015; Filsecker & Hickey, 2014; Osipov, Nikulchev, Volinsky, & Prasikova, 2015; Weiss, Knowlton, & Morrison, 2002). Game-based learning environments have significant potential to challenge and involve students in an active learning process. For example, Dominguez et al. (2013) have reported that students who completed a gamified experience obtained better scores in practical assignments. Similarly, Hwang, Wu, and Chen (2012) implemented an experimental model using an online game web-based problem-solving activity and reported a significantly improved experience in terms of students' learning attitudes, interest in learning, and acceptance of technology.

2.2. Online learning environment (OLE)

Following previous research, computer simulation, virtual laboratories, explanatory videos, and game-based activities have been integrated to provide virtual practical work and hands-on exercises (Estriegana-Valdehita et al., 2017).

Based on appropriate instructional strategies learned over several years of laboratory teaching, the OLE has been tested, evaluated, and improved year after year based on student and teacher feedback and taking into account students' main needs and deficiencies.

This OLE platform offers virtual laboratories and practical work that incorporate a range of randomly generated interactive and graphical activities, including numeral system exercises, truth tables, circuit simplification exercises, Karnaugh maps of different numbers of variables, minterms, and maxterms, circuit simulation exercises, circuit analysis and synthesis, logic gate and integrated circuit exercises, operations with the memory system, address, data, and control buses, and a simulator of an EPROM memory recorder.

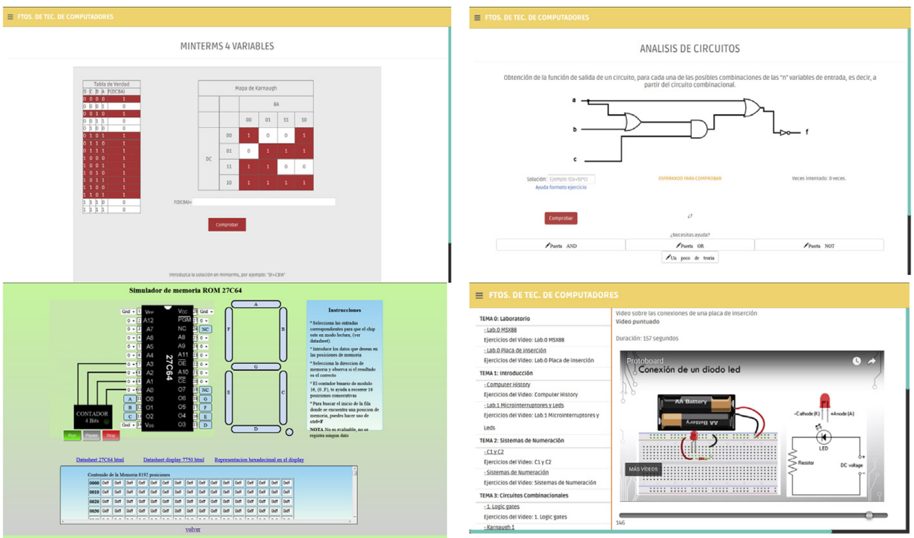

Fig. 1. OLE activities (in Spanish).

The OLE also includes game-based learning aimed at encouraging students to work with the application. Fig. 1 shows some examples of OLE activities. Students can choose the type of activity, watch videos, or see the results of the activities carried out and the medals obtained, comparing them with those of the rest of their classmates, thus promoting a level of competition that motivates the students. It is necessary to complete various stages of learning and perform several exercises correctly and consecutively to obtain badges. As the students obtain the different medals, these are displayed in color in the “Results” link, by section or globally. For example, to obtain the “memory position medal”, students must complete two consecutive activities from the “Memory End Position” exercises and another two from the “Address Bus Connections” simulator. Although students can attempt an unlimited number of exercises, they only have three chances to solve each activity before the correct result is displayed, another activity is randomly generated, and the sequence is initiated. The purpose of the badges is to increase student motivation, as this is a primary component that positively affects learning (Weiss et al., 2002).

Meanwhile, the aim of the videos is to engage students’ attention, enhance their understanding (Kay & Kletskin, 2012), motivate self-study, and create opportunities for discussion in the classroom (Wieling & Hofman, 2010). Moreover, students prefer video instructions for learning how to do something and simulations to familiarize themselves with environments over any other form of online instruction (Chan, 2010). Therefore, the OLE incorporates teaching videos that are between 5 and 10 min long, which is the approximate attention span of most students. Until a video has been viewed in full, it cannot be rewound or fast-forwarded. Once students have watched the video, they can access the questions to evaluate their understanding.

Teaching videos condense instructions and the most relevant subject matter, while virtual laboratories, simulations, and practical work reinforce the content presented. In previous studies, we assessed the efficiency of this OLE and its relationship with learning. Thus, in (Estriegana-Valdehita et al., 2017, we reported that its use facilitated an active learning approach and yielded an undoubtedly positive experience and appreciation of both the OLE learning environment itself and the active learning strategies it enabled in the classroom, improving learning achievement and performance in terms of grades. In addition, in (Estriegana, Medina-Merodio & Barchino, 2019), we reported that the OLE presented a positive relationship with competence acquisition and the learning outcomes measured.

2.3. Technology acceptance model (TAM)

The increased demand for e-learning resources and technological learning tools in higher education also implies a growing need to understand the prerequisites and variables that affect student acceptance, intention to use, and adoption of these tools.

The technology acceptance model (TAM) (Davis, 1986, 1989) is the best-known and most widely employed model to understand acceptance and adoption of information technology, information systems, and innovations, and it has been the subject of numerous studies since its inception (Davis, 1986). The TAM explains user motivation by means of 3 factors: Ease of use, usefulness, and attitude toward using. Several studies have attempted to extend and modify the TAM by proposing additional variables that may contribute to acceptance of technological innovation. Venkatesh and Davis (2000) developed and tested a theoretical extension of the TAM called TAM2, which explained perceived usefulness and intention to use in terms of social influence and cognitive instrumental processes. Later, Venkatesh, Morris, Davis, and Davis (2003) formulated the unified theory of acceptance and use of technology (UTAUT), which integrated elements across eight prominent TAM-based models.

TAM is a well-regarded and widely validated theory of technology acceptance and use. Yousafzai, Foxall, and Pallister (2007) conducted a meta-analysis of 145 articles on the TAM and most of the reviewed studies found that there was a direct relationship between perceived ease of use and usage behavior and that usefulness exerted a significant influence on behavioral intention.

Researchers have applied the TAM in diverse areas and different ways. For example, the TAM has been widely researched outside of health care (e.g., Holden & Karsh, 2010) and to explore the use of smartphone credit cards (e.g., Ooi & Tan, 2016). However, the TAM has primarily been used to study acceptance of technology with regard to innovative methods and tools in education, for example to verify the process whereby university students adopt and use e-learning resources (e.g., Park, 2009) or to investigate students' acceptance of blended e-learning systems (e.g., Al-Azawei, Parslow, & Lundqvist, 2017; Padilla-Meléndez, Aguila-Obra, & Garrido-Moreno, 2013). The TAM has also been employed to analyze students’ behavior regarding the use of new technologies in education, such as YouTube (e.g., Lee & Lehto, 2013), mobile technologies (e.g., Briz-Ponce, Pereira, Carvalho, Juanes-Méndez, & García-Peñalvo, 2017; Huang, Lin, & Chuang, 2007), and blogs (e.g., Tajuddin, Mustapha, Zaini, & Abd Aziz, 2012), or the adoption of cloud computing in education (e.g., Arpaci, 2017). Other studies have used the TAM to assess acceptance of learning management systems (LMS) by students (e.g., Liaw, 2008; Wu, Chang, Hsu, & Chen, 2010) or by academic staff (e.g., Radif, Fan, & McLaughlin, 2016).

However, despite being the most popular model for explaining and predicting diverse technological systems, there is a lack of studies exploring students’ acceptance of an online learning system for practical work that extends practical e-learning frameworks by incorporating virtual laboratories, hands-on exercises, instructional videos, and a game-based learning methodology.

Furthermore, despite the vast number of studies confirming TAM robustness, several researchers have also indicated some limitations of the model. Chuttur (2009) summarized limitations and criticisms from a selective list of published articles on the model. He categorized these limitations into three groups: 1) The methodology used to test the TAM; for example, most TAM studies have used self-reported usage data, which is a subjective and therefore unreliable measure (Legris, Ingham, & Collerette, 2003); 2) TAM variables and relationships; for example, different approaches to technology use (i.e., voluntary or obligatory) can produce different results; and 3) the core theoretical foundation underlying the TAM; for example, Bagozzi (2007) has highlighted the poor theoretical relationships between the different TAM constructs. Chuttur (2009) concluded that research on the TAM lacked sufficient rigor and relevance to render it a well-established theory.

In addition, some researchers have claimed that TAM factors alone may be insufficient to predict acceptance of technology and have proposed including other variables (e.g., Edmunds, Thorpe, & Conole, 2012; Legris et al., 2003).

3. Research model and hypotheses

Based on previous research, a theoretical model was developed using the TAM as a framework to understand the role of individual factors in users' acceptance of OLE learning resources. Each of the hypotheses presented below corresponds to each path in the SEM and forms part of the aforementioned objective. Davis (1989) defined attitude toward using a new system (ATU) as "an individual's overall affective reaction to use of the system", while Venkatesh et al. (2003) defined behavioral intention to use a system (BI) as "the degree of an individual's belief that he or she will continue to use the system". In addition, the more favorable students' attitude toward using a new system, the greater their use intentions would be (Ajzen, 1991). Thus, we hypothesized that positive attitudes toward using OLE resources would be significantly associated with the intention to use **(H1).**

In line with Davis' (1989) definitions:

Perceived usefulness (PU) is "the degree to which a person believes that using a particular system would enhance his or her job performance", where useful is defined as "capable of being used advantageously". Therefore, if students perceive advantages in using the educational resources for self-study and hands-on exercises, their attitude toward use of these resources will be more positive. Consequently, we hypothesized that perceived usefulness (PU) would be a significant factor in predicting variance in: 1) students' attitude toward using the OLE system **(H2)** and 2) students' intention to use these learning tools **(H3)**.

Perceived ease of use (PEOU), in contrast, refers to "the degree to which a person believes that using a particular system would be free of effort", where ease is defined as "freedom from difficulty or great effort". It seems reasonable to assume that the easier it is to understand and perform OLE activities, the more positive attitudes will be toward using the OLE. Hence, we hypothesized that perceived ease of use (PEOU) would be a significant factor in predicting variance in students' attitude toward using the OLE system **(H4**). We also hypothesized that viewing OLE as easy to use would have a positive impact on the perceived usefulness of OLE tools **(H5)**.

Nevertheless, these factors alone appear insufficient to predict acceptance and adoption of the OLE and its virtual tools for laboratory and practical work.

3.1. Perceived satisfaction

In our model, the cognitive perception of satisfaction when using OLE learning tools has been added to the cognitive domain of the TAM. Other authors have investigated students' perceived satisfaction (PS) as a critical issue in better understanding learners' behavioral intention to use an e-learning system. According to Liaw (2008), perceived satisfaction enhances learners' perceptions of technology that promotes their participation in the learning processes. Liaw concluded that perceived satisfaction and perceived usefulness positively affect learners' behavioral intention to use e-learning resources. For their part, So and Brush (2008) affirmed that students' degree of satisfaction with courses plays an important role in evaluating the effectiveness of distance learning. Similarly, Wu, Chang, et al. (2010) and Wu, Tennyson, et al. (2010) examined the determinants of student satisfaction with learning in a blended e-learning system, defining satisfaction as the sum of students' behavioral beliefs and attitudes when aggregating all the benefits they received from using the blended e-learning system. Moreover, the results obtained by Chiu, Hsu, Sun, Lin, and Sun (2005) suggest that users' intention to continue is determined by satisfaction. Another recent study (Al-Azawei et al., 2017) found a weak effect of learning styles in predicting satisfaction and blended e-learning acceptance.

Based on the previous studies, we hypothesized that students' perceived satisfaction (PS) when using OLE resources would positively impact on their perceived usefulness **(H6**), on students' attitude toward using the OLE system **(H7**), on their intention to use the OLE **(H8**) and on use of the OLE **(H9**). In addition, we hypothesized that perceived satisfaction would be significantly affected by perceived ease of use of the system **(H10**).

3.2. OLE system design factors: efficiency and playfulness

In the TAM proposed by Davis (Davis, 1986, 1989), ease of use and usefulness are the two main factors that influence technology usage behavior. Influenced by the characteristics and quality of OLE activities (virtual labs, simulators, videos, and interactive learning activities), students perceive the OLE system as efficient and playful. Hence, the proposed model extends the TAM by adding efficiency and playfulness as additional factors, which are expected to have a significant impact on perceptions of usefulness, ease of use, and satisfaction. Efficiency and playfulness are not included in the initial theoretical framework of the TAM, these factors constitute system design characteristics of the OLE that have been measured in previous studies (Estriegana-Valdehita et al., 2017; Estriegana et al., 2019).

Efficiency is the ability to accomplish a task with the minimum expenditure of time and effort. According to Liaw (2008), e-learning efficiency can be influenced by multimedia instruction, interactive learning activities, and e-learning system quality. In the OLE, teaching videos condense the most relevant subject matter, while virtual laboratories and simulation reinforce the content presented. Moreover, hands-on and training activities, which are especially important in technological degrees, give students the opportunity to study at their own pace, wherever, whenever, and as often as they want. This provides more time in the classroom to learn efficiently, harmonizing in-class and out of class time.

We hypothesized that efficiency would positively impact on perceived usefulness (PU) **(H11)**, on perceived ease of use (PEOU)

(H12), and on perceived satisfaction (PS) with OLE tools **(H13)**.

Perceived playfulness or enjoyment can be defined as an intrinsic belief or motive, which is shaped by the individual's experiences of the environment (Moon & Kim, 2001). More specifically, Moon and Kim considered that individuals who have a more positive playfulness belief in use of the World Wide Web should view their interactions more positively than those who interacted less playfully. Therefore, if a student perceives the use of OLE tools as playful or enjoyable, he or she is more likely to have a favorable attitude and a greater intention to use them.

Several studies have focused on students' perception of playfulness in educational environments or with learning tools. Thus, for example, Moon and Kim (2001) found that perceptions of playfulness appear to influence user attitudes toward using the World Wide Web. In addition, perceived playfulness is an important factor in student use of blogs (Tajuddin et al., 2012) and in student attitudes regarding the intention to use Moodle in a blended classroom (Padilla-Meléndez, del Aguila-Obra, & Garrido-Moreno, 2013). Furthermore, playfulness affects perceived learning performance (Liao, Huang, & Wang, 2015). However, perceived playfulness is not always an important factor in determining attitudes toward using technological resources. For example, it does not predict a significant relationship with intention to use mobile technologies (Kim-Soon, Ibrahim, Ahmad, & Sirisa, 2015), and it can also distract students from the task at hand (Ejsing-Duun & Karoff, 2014).

Nevertheless, students' perception of playfulness and enjoyment is especially relevant in online or virtual learning environments. Consequently, one of the characteristics of the OLE is the use of a game-based learning methodology to promote the experience of study as a game and trigger feelings of pleasure, enjoyment, and fun resolving a challenge, receiving badges or medals, or comparing achievements with those of classmates.

We hypothesized that playfulness would be a significant factor that positively influenced perceived usefulness (PU) **(H14)**, perceived ease of use (PEOU) **(H15)** and perceived satisfaction (PS) with the OLE **(H16)**.

3.3. Use of the OLE

Our final hypothesis was that there would be a significant and positive relationship between the intention to use the OLE system and the actual use made of it **(H17)**.

Most studies on the TAM have explained and predicted the voluntary use of systems, but very few have considered obligatory use of systems (Yousafzai et al., 2007). However, most teachers or academic institutions require students to use learning systems or tools. In our study, although use of the OLE was not entirely obligatory to pass the subject (marked out of 10), completion of all OLE activities, videos, and exercises during the course was worth 1.5 points. Nevertheless, the real reward was time devoted to study and practice, which had a significant impact on performance and learning outcomes, as shown in previous studies (Estriegana-Valdehita, Barchino-Plata, & Medina-Merodio, 2016; Estriegana-Valdehita et al., 2017; Estriegana et al., 2019). Another motivation to use the OLE was that prior autonomous study subsequently facilitated the use of active learning strategies, collaborative projects, and game-based learning techniques and activities with mobile applications in the classroom.

After watching each video, students had to answer questions correctly to obtain badges. In the case of activities and simulations, it was necessary to complete several learning stages and various exercises correctly and consecutively to achieve badges, which obliged students to repeat and play with the applications. In addition, it is worth noting that students were observed to continue using the OLE as a study tool even after they had obtained the points assigned to each activity or video viewing, especially shortly before examinations (Estriegana-Valdehita et al., 2016).

All components of the OLE are integral to effective virtualization of accessible and motivated autonomous practical work. In our study, use of the OLE was assessed by means of the different activities students carried out and recorded in a database. Thus, ActivOLE referred to medals and points obtained for the different activities and simulations carried out on the OLE platform, including NS (numeral system exercises), KM (circuit simplification exercises: Karnaugh maps with minterms and maxterms of 2, 3, and 4 variables), Mem (exercises on memory system and memory simulator, data, address, and control buses or EEprom recorder), and CC (combinational circuits: truth tables, circuit synthesis, circuit analysis); Video referred to medals and points obtained for viewing the 25 videos; and ExVideo referred to completion of video-related activities.

With respect to student use of the OLE environment, of the total 245 students who finished the course, 46% of students completed all or more than 75% of OLE activities, 29% of students completed between 50% and 75%, 17% of students completed between 25% and 50%, and 8% of students completed less than 25% of OLE activities.

The conceptual research framework is shown in Fig. 2.

4. Research method

An online questionnaire was designed to test our hypotheses. O'Leary (2017) has identified several strengths of this research method, and has recommended adapting existing questionnaires. Thus, our questionnaire was developed taking into account the other models reviewed and following several criteria as guidelines.

4.1. Instrument

Items for each variable in the study were adapted from scales that have been validated in previous studies. TAM scales of attitude toward using, behavioral intentions to use, perceived usefulness, and perceived ease of use were measured using items adapted from (Davis, 1989) and (Venkatesh & Davis, 2000). Questions on perceived satisfaction (PS) were adapted from (Chiu et al., 2005), also

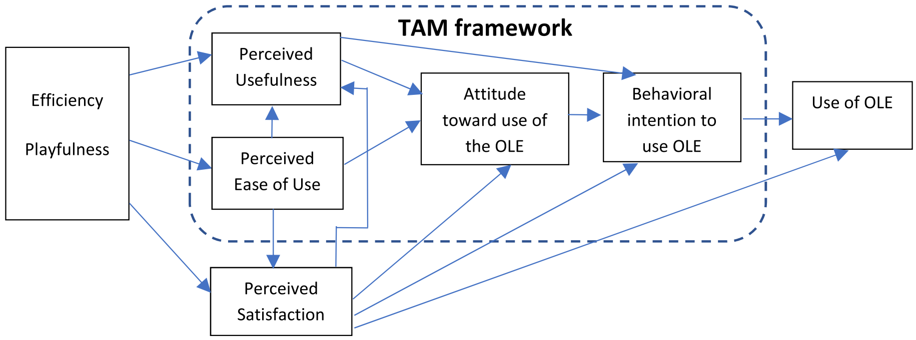

Fig. 2. Conceptual research framework.

used in (Al-Azawei et al., 2017). Items used to evaluate OLE efficiency (EFF) were based on the web-based learning environment inventory (WEBLEI) (Chang & Fisher, 2003, pp. 1–20; Ozkok, 2013) adapted from (Tobin, 1998). Questions on perceived playfulness (PP) were adapted from (Padilla-Meléndez et al., 2013).

The questionnaire used a 5-point bipolar Likert scale (Likert, 1932), with responses ranging from 1 "completely disagree" to 5 "completely agree", adopting the usual method to measure variables that are not directly quantifiable (Hair, Ringle, & Sarstedt, 2013).

To minimize errors in items related to variance, we used simple questions and easily understood language. No research intentions or hypotheses were mentioned, items were clearly formulated, abstract questions or terms were avoided, all terms were familiar to the students, and there were no double-barreled items. The questionnaire was revised by several experts to determine whether the questions were appropriate and confirm that the statements were unambiguous and easily understood; a few modifications were implemented following the feedback.

4.2. Participants and data collection

The analysis was conducted using data obtained from students taking the course Fundamentals of Computer Technology, a core subject in the first year of the Computer Engineering and Information Systems degree. The fundamental goal of this subject is to teach the basic level operation of a computer and the functional units at architectural level. Students study binary data (bits) processing at different levels of abstraction, from logic gates to basic electronic devices, and analyze and design combinational logic networks and synchronous and asynchronous machines.

Data were collected from students by administering a voluntary online questionnaire at the end of term. Although a total of 261 students were enrolled in the subject, some did not attend any classes or left the subject over the course of the year without performing any activity. Of 245 students remaining, all except 19 completed the questionnaire since they were highly motivated by the subject and the OLE. Thus, the full sample consisted of 226 students. Once incomplete or unclear responses had been omitted, this yielded a final sample of 223 students (189 males and 34 females) aged mostly 18 or 19 years old.

5. Data analysis

We conducted a regression analysis of latent variables, based on the optimization technique of partial least squares (PLS) to construct the model. Our study drew on SmartPLS 3.2.6, a multivariate technique for testing structural models that estimates the model parameters that minimize the residual variance of the entire model's dependent variables (Hair, Hult, Ringle, & Sarstedt, 2016). It does not require any parametric conditions and is recommended for small samples (Hulland, 1999).

5.1. Justification of sample size

Roldán and Sánchez-Franco (2012 p. 198) have indicated that the sample size issue is one of the main characteristics of PLS. The segmentation process used by the PLS algorithm renders it possible to divide complex models into subsets in order to calculate sample size based on the highest number of structural paths directed at a particular dependent latent variable. Although there are different, much less restrictive criteria, Reinartz, Haenlein, and Henseler (2009) have suggested increasing sample size to 100 in order to reach acceptable levels of statistical power. Although this has been a widely used criterion, Roldán and Cepeda (2016) have recommended not using the old heuristic rule of 10 cases per predictor suggested by (Barclay, Higgins, & Thompson, 1995), and instead proposed specifying the size effect for each regression while consulting the power tables developed by (Cohen, 1994) to obtain a more precise assessment. Likewise, Hair et al. (2016) have suggested using programs such as G*Power or G*Power 3.0 for a specific power analysis according to model specifications (Cohen, Rothstein, & Borenstein, 2001; Faul, Erdfelder, Lang, & Buchner, 2007).

To determine sample size, it is necessary to specify the expected effect size (ES) and the significant values for alpha (α) and power (β). In general terms, an alpha of .05 and a power of 80% are acceptable. These three values are then used to calculate sample size. In this case, a multiple regression study was conducted with four predictors, an average effect size (ES) of 0.15, an alpha of .05, and a

Table 1
Outer model loadings.

	Use of OLE	Att. Toward Use	Behavioral Intention to Use	Efficiency	Perceived Ease of Use	Perceived Usefulness	Playfulness	Satisfaction
ActivOLE	0.775							
ExVideo	0.953							
Video	0.945							
ATU2		0.897						
ATU3		0.915						
BI1			0.917					
BI2			0.930					
EFF1				0.745				
EFF2				0.828				
EFF3				0.807				
PEOU1					0.751			
PEOU2					0.887			
PEOU3					0.819			
PU1						0.896		
PU2						0.896		
PP1							0.865	
PP2							0.896	
PS1								0.870
PS2								0.922
PS3								0.897

power of .95, in line with Cohen (1994), to obtain the sample size.

The result of this analysis was N = 129 participants. Given that our available study sample consisted of 223 valid cases, our sample comfortably exceeded all criteria for performing an analysis of the measurement models and structural model.

5.2. Measurement model evaluation

Skewness assesses the extent to which a variable's distribution is symmetrical and kurtosis is a measure used to analyze the degree to which values for the variable analyzed cluster around the central area. An excessively peaked distribution indicates a very narrow distribution with most of the responses in the center (Hair et al., 2016).

Our results indicated that the measurement model was completely satisfactory since most kurtosis and skewness values for the indicators were within the acceptable range (-1 to $+1$), except for a few that exhibited a slight degree of non-normality (Hair et al., 2016). However, as the degree of skewness was not severe and because one of the two indicators measured the (reflective) construct, this deviation from normality was not considered an issue and the indicator was retained. All standardized loadings (λ) were greater than 0.707 (Table 1), indicating that individual item reliability was acceptable (Carmines & Zeller, 1979).

Simple reliability of the measurement scales used was calculated by means of Cronbach's alpha values, all of which were above 0.70 (Nunnally & Bernstein, 1994). Regarding composite reliability, all the indicator values were greater than 0.7 (Werts, Linn, & Jöreskog, 1974), indicating a high level of internal consistency reliability among latent variables. In the analysis of variance, all values for the average variance extracted (AVE) were above 0.50 (Fornell & Larcker, 1981), exceeding the minimum acceptable values for validity (Table 2).

In addition, Fornell and Larcker (1981) have suggested that the square root of the AVE in each latent variable can be used to establish discriminant validity; thus, to confirm discriminant validity between constructs, this value must be higher than the correlation between constructs. Table 3 presents the square roots of the AVE (on the diagonal) and the correlations between constructs. The value is higher than other correlation values between latent variables, indicating acceptable discriminant validity of the measurements.

As shown in Table 4, we also applied discriminant validity measures using the heterotrait-multitrait (HTMT) method (Henseler, Ringle, & Sarstedt, 2015), which indicates the mean of the heterotrait-heteromethod correlations relative to the geometric mean of

Table 2
Cronbach's alpha coefficients, Rho_A, construct reliability, and average variance extracted.

Construct	Cronbach's alpha	Rho_A	Composite reliability	Average variance extracted (AVE)
Use of OLE	0.872	0.894	0.923	0.801
Attitude Toward Using	0.783	0.788	0.902	0.822
Behavioral Intention to Use	0.828	0.832	0.921	0.853
Efficiency	0.707	0.712	0.837	0.631
Perceived Ease of Use	0.755	0.758	0.860	0.674
Perceived Usefulness	0.754	0.754	0.890	0.802
Playfulness	0.711	0.718	0.873	0.775
Satisfaction	0.879	0.894	0.925	0.804

Table 3
Discriminant validity matrix (Fornell-Larcker criterion).

	Use of OLE	Att. Toward Using	Behav. Intention to Use	Efficiency	Perc. Ease of Use	Perc. Usefulness	Playfulness	Satisfaction
Use of OLE	0.895							
Attitude Toward Using Use	0.274	0.906						
Behav. Inten. to Use	0.316	0.557	0.924					
Efficiency	0.381	0.447	0.376	0.794				
Perceived Ease of Use	0.358	0.379	0.589	0.408	0.821			
Perceived Usefulness	0.393	0.603	0.579	0.546	0.507	0.896		
Playfulness	0.308	0.620	0.450	0.436	0.490	0.616	0.880	
Satisfaction	0.355	0.557	0.594	0.536	0.568	0.633	0.541	0.897

Table 4
Discriminant validity matrix (heterotrait-monotrait ratio criterion).

	Use of OLE	Att. Toward Use	Behav. Intention to Use	Efficiency	Perc. Ease of Use	Perc. Usefulness	Playfulness	Satisfaction
Use of OLE								
Attitude Toward Using Use	0.331							
Beh. Intention. to Use	0.368	0.692						
Efficiency	0.490	0.594	0.486					
Perceived Ease of Use	0.442	0.492	0.743	0.561				
Perceived Usefulness	0.486	0.782	0.730	0.742	0.671			
Playfulness	0.394	0.830	0.583	0.606	0.664	0.840		
Satisfaction	0.403	0.656	0.686	0.666	0.688	0.771	0.677	

the average monotrait-heteromethod correlation of both variables. We used a conservative criterion of 0.85, which is associated with sensitivity levels of 95% or better. With construct correlations of 0.70, the specificity rates for HTMT 0.85 are close to 100%. We found that the HTMT ratio for group-focused and individual-focused transformational leadership, at .83, was below the 0.85 cut-off, and substantially below the 0.95 cut-off recommended for conceptually close constructs (Henseler et al., 2015). This provides good support for our claims of discriminant validity between our individual and group measures (Henseler et al., 2015).

5.3. Structural model analysis

The model shown in Fig. 3 was constructed from a review and analysis of the literature.

The PLS program can generate t statistics for significance testing of both the inner and outer model, using the procedure called bootstrapping (Chin, 1998). In this procedure, a large number of subsamples (5000) are taken from the original sample with replacement to give bootstrap standard errors, which in turn give approximate T-values for significance testing of the structural path.

The results of the bootstrapping procedure were as follows: All the R^2 (R-squared) values ranged from 0 to 1 (Table 5). The higher

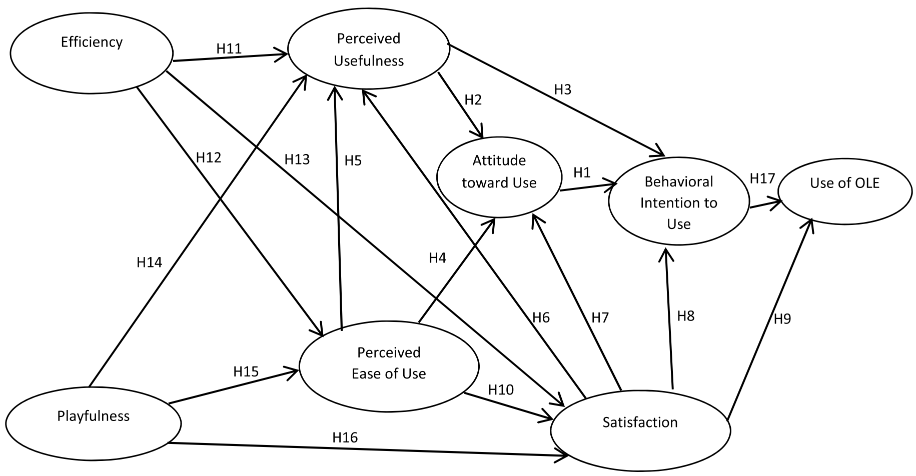

Fig. 3. Structural model (baseline model).

Table 5
Structural model results.

	R^2	Sample Mean (SM)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values	Q^2
Use of OLE	0.143	0.153	0.060	2.401	0.008	0.106
Attitude Toward Using	0.415	0.427	0.069	6.048	0.000	0.321
Behav. Intention to Use	0.456	0.471	0.082	5.535	0.000	0.363
Perceived Ease of Use	0.287	0.302	0.058	4.923	0.000	0.180
Perceived Usefulness	0.545	0.555	0.067	8.111	0.000	0.405
Satisfaction	0.478	0.489	0.059	8.135	0.000	0.348

the value, the greater the model's predictive capacity for that variable. Because R^2 should be sufficiently high for the model to reach a minimum level of explanatory power, R^2 values must be greater than 0.10 with a significance of $t > 1.64$ (Falk & Miller, 1992).

Fig. 4 and Table 5 show the variance explained by R^2 in the dependent constructs and the path coefficients for the model. They were not below 0.10, indicating that the independent explanatory variables were acceptable.

Standardized regression coefficients show estimates of structural model relationships, in other words the hypothesized relationships between constructs. Hence, the algebraic sign is analyzed if there is change in sign; the magnitude and statistical significance (T statistics) was greater of 1.64 (t (4999), one-tailed test). Next, the hypotheses were checked and validated, and the relationships were positive, mostly with high significance, as shown in Table 6.

When percentile bootstrap was applied to generate a 95% confidence interval using 5000 resamples, hypothesis H1 to H17 were supported because their confidence interval did not include zero (Table 6). Thus, all hypotheses were confirmed. These results complete a basic analysis of PLS-SEM in our research. The result for PLS-SEM is shown in Fig. 4.

Table 7 shows the amount of variance that each antecedent variable explained on each endogenous construct. R^2 figures were greater than 0.14 for almost all values. Thus, cross-validated redundancy measures show that the theoretical/structural model has predictive relevance ($Q^2 > 0$).

6. Discussion

Structural equation modeling (SEM) was employed to explain students' acceptance and adoption process of an online learning environment (OLE) incorporating technological tools with which students can perform laboratory practicals essential to their learning. The structural model is based on the technology acceptance model (TAM), which includes perceived usefulness, perceived ease of use, attitude toward using, and behavioral intention to use the OLE. Moreover, following other researchers' criteria regarding extension of the TAM to improve its effectiveness (e.g., Edmunds et al., 2012; Legris et al., 2003), we have proposed including perceived efficiency, playfulness, and satisfaction to enhance the TAM and better understand the factors that affect the adoption of virtual practical exercises and laboratories.

Our results show that the model is completely satisfactory. The reliability of each individual item and values for simple and composite reliability were acceptable and a high level of internal consistency reliability has been demonstrated among latent variables. Furthermore, the values for validity and discriminant validity of the measurements were also acceptable. The independent explanatory variables were satisfactory.

All the hypotheses were validated, and the relationships were positive, mostly with a high level of significance. The results confirm our hypotheses regarding the TAM (from H1 to H5); consequently, our research model clearly contributes to the existing

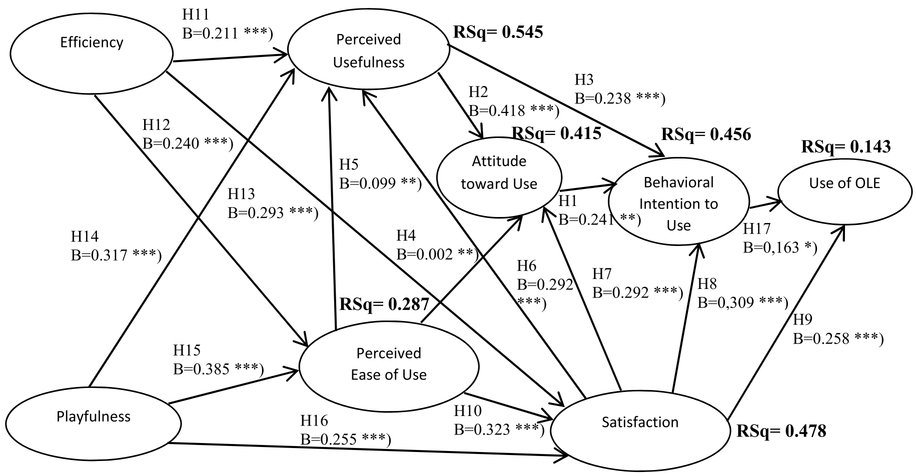

Fig. 4. Results of testing model significance * $P < 0.05$.** $P < 0.01$.*** $P < 0.001$.

Table 6
Structural model results. Path significance using percentile bootstrap 95% confidence interval (n = 5000 subsamples).

Hyp	Results	Influence	SPC	Sample Mean (M)	Std. Dev. STDEV	T Statis. |O/STDEV|	P Value	+/− change
H1	Accepted (**)	Attitude Toward Using - > Behavioral Intention to Use	0.241	0.239	0.097	2.476	0.007	No
H2	Accepted (***)	Perceived Usefulness - > Attitude Toward Using	0.418	0.419	0.082	5.118	0.000	No
H3	Accepted (***)	Perceived Usefulness - > Behavioral Intention to Use	0.338	0.337	0.084	4.045	0.000	No
H4	Accepted (**)	Perceived Ease of Use - > Attitude Toward Using	0.177	0.180	0.064	2.777	0.003	No
H5	Accepted (**)	Perceived Ease of Use - > Perceived Usefulness	0.194	0.198	0.073	2.647	0.004	No
H6	Accepted (***)	Satisfaction - > Perceived Usefulness	0.292	0.296	0.080	3.631	0.000	No
H7	Accepted (***)	Satisfaction - > Attitude Toward Using	0.414	0.416	0.076	5.455	0.000	No
H8	Accepted (***)	Satisfaction - > Behavioral Intention to Use	0.479	0.479	0.079	6.032	0.000	No
H9	Accepted (***)	Satisfaction - > Use of OLE	0.336	0.335	0.077	4.375	0.000	No
H10	Accepted (***)	Perceived Ease of Use - > Satisfaction	0.323	0.327	0.063	5.119	0.000	No
H11	Accepted (***)	Efficiency - > Perceived Usefulness	0.343	0.342	0.064	5.325	0.000	No
H12	Accepted (***)	Efficiency - > Perceived Ease of Use	0.240	0.244	0.069	3.483	0.000	No
H13	Accepted (***)	Efficiency - > Satisfaction	0.370	0.371	0.062	5.935	0.000	No
H14	Accepted (***)	Playfulness - > Perceived Usefulness	0.466	0.464	0.057	8.236	0.000	No
H15	Accepted (***)	Playfulness - > Perceived Ease of Use	0.385	0.390	0.071	5.392	0.000	No
H16	Accepted (***)	Playfulness - > Satisfaction	0.379	0.381	0.064	5.967	0.000	No
H17	Accepted (*)	Behavioral Intention to Use - > Use of OLE	0.163	0.163	0.087	1.866	0.031	No

Note: t (0.05, 4999) = 1.645158499, t (4999 0.01.) = 2.327094067, t (0.001, 4999) = 3.091863446 * P < 0.05.**P < 0.01.***P < 0.001.ns. Not significant based on t (4999), one-tailed test.

Table 7
Effects on endogenous variables (extended model).

Dependent Variable	R^2	Q^2	Antecedents	Path Coeff.	Correlation	Explained Variance (%)
Use of OLE	0.143	0.106				14.3
			H17: Beh. Intention to Use	0.163	0.316	5.15
			H9: Satisfaction	0.258	0.355	9.15
Behavioral Intention to Use	0.456	0.363				45.6
			H3: Perceived Usefulness	0.238	0.579	13.78
			H1: Attitude toward Using	0.241	0.557	13.42
			H8: Satisfaction	0.309	0.594	18.35
Attitude Toward Using	0.415	0.321				41.5
			H2: Perceived Usefulness	0.418	0.603	25.2
			H4: Perceived Ease of Use	0.002	0.379	0.75
			H7: Satisfaction	0.292	0.557	16.06
Perceived Usefulness	0.545	0.405				54.5
			H11: Efficiency	0.211	0.546	11.5
			H5: Perceived Ease of Use	0.099	0.507	5.01
			H14: Playfulness	0.317	0.616	19.52
			H6: Satisfaction	0.292	0.633	19.48
Perceived Ease of Use	0.287	0.180				28.7
			H12: Efficiency	0.240	0.408	9.79
			H15: Playfulness	0.385	0.490	18.86
Satisfaction	0.478	0.348				47.8
			H13: Efficiency	0.293	0.536	15.70
			H10: Perceived Ease of Use	0.323	0.568	18.34
			H16: Playfulness	0.255	0.541	13.79

evidence about the robust construction of the TAM (Davis, 1986, 1989; Venkatesh & Davis, 2000). Of particular note is that perceived usefulness affects attitude toward using the OLE (H2) (25.2%), contrasting with perceived ease of use (H4), where the value was low because it influenced attitude via satisfaction (H7), which affected attitude, explaining 16.06%.

In addition, as shown in Table 7, perceived satisfaction positively affected perceived usefulness (H6), explaining 19.48%. Moreover, satisfaction played a key role in behavioral intention to use the OLE (H8), as suggested Chiu et al. (2005), explaining 18.35%, and in use of OLE (H9), explaining 9.15%. In fact, satisfaction was more significant, explaining use of the OLE system rather than behavioral intention to use it (H17) (5.15%). Regarding the value for the use made of the OLE applications, measured by means of the different activities and exercises carried out by students, it is noteworthy that this contrasted with expected use as measured by the value for students' behavior.

In turn, satisfaction was jointly determined by perceived ease of use (H10), which explained 18.34%, perceived efficiency (H13), explaining 15.70%, and perceived playfulness (H16), explaining 13.79%.

Multimedia instruction, interactive learning activities, and e-learning system quality are all critical predictors of e-learning acceptance and motivation among users (Liaw, 2008). Students' perception of the efficiency and playfulness of virtual laboratories, simulators, interactive learning activities, videos, and game-based learning all positively influenced perceived satisfaction, perceived usefulness, and perceived ease of use. The results show that 11.5% of perceived usefulness was explained by efficiency (H11) and 19.52% by playfulness (H14). Meanwhile, 9.79% of perceived ease of use was explained by efficiency (H12) and 18.86% by playfulness (H15). By definition, there is a logical relationship between the TAM factors ease of use and usefulness and the OLE factor of efficiency, a characteristic of OLE system design that has been analyzed in other studies (Estriegana-Valdehita et al., 2017; Estriegana et al., 2019). Although this relationship has been corroborated in the present study, we nevertheless found that playfulness and satisfaction affected perception of usefulness to a greater extent than the OLE factor of efficiency. Similarly, playfulness also affected ease of use to a greater extent than efficiency.

Besides the above, although our model does not consider the indirect total effect of playfulness and efficiency on attitude, behavioral intention, and actual use, these were also measured and found to be significant, as indicated by other authors. Thus, playfulness influences user attitude toward using the World Wide Web (Moon & Kim, 2001) and toward use of Moodle in a blended classroom (Padilla-Meléndez et al., 2013).

7. Conclusions

This study contributes to the existing literature on student acceptance and behavior regarding new educational technologies. Although there are numerous studies on the TAM, few have focused on virtual laboratories and interactive activities designed to facilitate virtual hands-on and laboratory work, essential aspects of learning in technological areas. Our study included new factors in the TAM to better understand students' behavior regarding potential acceptance or rejection of these online learning tools, namely, perceived efficiency, playfulness, and satisfaction.

Our results indicate the following: First, the TAM is once again confirmed. Our results proved the TAM to be a good theoretical tool to understand users' acceptance of a system such as the OLE, which includes virtual laboratories, interactive simulations, and activities, as well as teaching videos. Second, efficiency and playfulness are factors that positively influence students' adoption of this technology. Consequently, virtual activities and practicals should be properly designed to provide students with efficient practical experiences. Likewise, virtual tools should be designed with a playful approach, as playfulness and enjoyment are crucial to engage learners in the subject matter and the learning process, and to improve motivation and acceptance of these tools. Third, the degree of student satisfaction using an e-learning system is a critical issue to better understand students' behavior and intention to use this system. Perceived satisfaction is one of the factors that exert most influence on student acceptance, having a positive impact on perceived usefulness, attitude toward using the OLE system, behavioral intention to use the OLE, and actual use of the OLE.

Our OLE system has been developed ad hoc from scratch, which implies certain limitations as regards flexibility and adaptability for other courses. Web resources also add complexity when creating virtual laboratories. Consequently, further research is required to achieve standardization. In addition, our methodology also presents some limitations that should be noted. First, the use of self-reported data can give rise to common method variance. However, most studies on the TAM have employed self-reported use data and since our study drew on structural equation modeling (SEM), which facilitates identification and confirmation of relationships between multiple variables and enables assessment and elimination of variables characterized by weak measurement, the error in the model was minimized. Second, the total variance explained for the dependent variable use of the OLE was only 14.3%, leaving 85.7% unexplained; hence, it is possible that other predictors were excluded from the study. Third, our study did not include individual difference factors that might affect the model, such as sex or previous experience with the OLE. It was not possible to evaluate either of these two factors due to the small sample in both cases (of 223 students, only 34 were women and only 29 were repeating the subject and already knew how to use the learning tools). Assessment of other types of individual factor was ruled out in this study to avoid administering an excessively long questionnaire to students.

Our study only evaluated several latent variables; however, in the future, we intend to conduct longitudinal research using a similar OLE in other subjects. This proposed study will evaluate students' experience with each OLE tool as well as their expectations or initial motivation to use these tools. In addition, in future work, we intend to develop more modules to provide greater communication and interactivity between students, increase system scalability and flexibility, and use the OLE in other courses.

In scientific and technological areas where laboratory courses are taught alongside theoretical classes, virtual laboratories, simulators, and interactive tools supported by explanatory videos and game-based elements can prove indispensable resources. Therefore, our study may be useful in encouraging other teachers to expand the e-learning framework by developing and implementing web-based activities for practical work, considering not only their usefulness and efficiency, but also their playfulness and student satisfaction when using them.

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